International Energy Agency Cooperative Agreement on Environmental, Safety, and Economic Aspects of Fusion Power
4th Specialists Meeting on Component Failure Rate Data
IEA ESE/FP Task 5, Failure Rate Database
Meeting Minutes for 10 October 2003

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Jerry Levine, the Head of the Environment, Safety and Health Division at the Princeton Plasma Physics Laboratory (PPPL), opened the meeting with a welcome to PPPL. Lee Cadwallader then presented the day's agenda.

Jerry Levine began the day's presentations with a brief overview of the laboratory. PPPL was founded in 1951 and is sited on 72 acres near US Route 1 in New Jersey. There have been a number of fusion machines sited at PPPL, including the Princeton Large Torus (PLT), the Tokamak Fusion Test Reactor (TFTR), and the National Spherical Torus Experiment (NSTX). The National Compact Stellarator Experiment (NCSX) will be built on the "C" site, where the PLT was housed.

PPPL is the National Center for Plasma and Fusion Science. Besides the professional staff of ~400 at PPPL, there are usually about 10 graduate students working at any time.

TFTR began operation in December 1982, and was shut down in April 1997. In its last years TFTR burned tritium fuel for a record making 10.7 MW thermal power created by the plasma. Jerry pointed out that the Joint European Torus in the United Kingdom has surpassed this record by higher power shots since 1997. The NSTX began operation on February 12, 1999; 10 weeks ahead of schedule and within budget. The machine was built, and has operated, safely. The NSTX is similar to the Mega-Ampere Spherical Tokamak (MAST) in the United Kingdom. The NCSX has been in design for more than two years, it is scheduled to begin construction in early 2004, with first plasma operation in 2007. The cost is $80M USD. The NCSX will be built in the old Princeton Large Torus/Princeton Beta Experiment test cells at the PPPL C-site.

Then Jerry Levine gave a presentation on the safety work that has been conducted for fusion machines at Princeton, primarily the TFTR. He described the TFTR safety analysis process. The Preliminary Safety Analysis Report (PSAR) was developed in 1976-1977, and was approved by the US Department of Energy (USDOE) in 1978. In the US method, PSAR approval is needed before any site construction work could proceed. In this case, the PSAR approval was needed before concrete could be poured for the Test Cell. The Final Safety Analysis Report was developed in 1980-1982, and was approved by the USDOE in 1982. There was an FSAR amendment for deuterium-tritium operations at TFTR. The USDOE approved this amendment in 1992.

There was no model for fusion experiment safety work at the time. They borrowed applicable format and content guidance from fission reactor PSAR and FSAR direction.

They used deterministic Failure Modes and Effects Analysis, and minimal probabilistic analysis, as was the prevailing safety approach at that time. The TFTR FSAR was two volumes and about 1000 pages.

The worst-case accident in the PSAR was a structural collapse of the test cell with a maximum tritium inventory in the vacuum vessel and associated systems. The 6,100 Curies of tritium as HTO, released at ground level, would result in a 2,730 mrem (27.3 mSv) dose at the site boundary. There were over 300 comments from USDOE reviewers and these took 5 months to resolve. In 1988, PPPL had the National Oceanic and Atmospheric Administration (NOAA) perform tracer gas tests to obtain site-specific Chi/Q atmospheric dispersion coefficient values. Using preliminary site-specific values for radiation release calculations, a new worst-case release of 14,600 Ci of HTO resulted in a dose of only 660 mrem (6.6 mSv) in the original FSAR.

In 1988, PPPL had the National Oceanic and Atmospheric Administration (NOAA) perform tracer gas tests to obtain more accurate site-specific Chi/Q atmospheric dispersion coefficient values.

For the FSAR D-T amendment, the worst-case accident was a pipe break with air ingress to a tritium storage bed. While Canadian tests have shown that this event is not as energetic as initially thought, it remained the worst-case event for the FSAR. In that event, 25,000 Ci of HTO would be stacked, with a maximum dose of 140 mrem (1.4 mSv). To consider beyond design basis accidents, the heating, ventilation and air conditioning (HVAC) was assumed to fail, yielding a ground level release.

Tritium was the most important radionuclide at TFTR, and the hazard category of TFTR was set by the tritium inventory. Since the site limit was 50,000 Ci, TFTR was USDOE hazard category 3 (between 16,000 and 300,000 Ci of tritium), a Low Hazard facility.

PPPL has had 630 Unresolved Safety Question Determinations between 1993 and 2001. These determinations kept the safety analysts quite busy.

There were several special studies that were carried out during the TFTR years that were important to support safety at PPPL. The two most important were:

1) The NOAA study. The typical Gaussian plume models for atmospheric dispersion and dilution are for more open terrain sites. PPPL has buildings and groves of trees that produce turbulence; the turbulence produces enhanced mixing and dispersion of the plume. The NOAA team set up 98 sampling sites and took 50,000 readings of 4 releases. One release was stacked, and three were varying ground level release locations. At PPPL the dilution is 16 times more than the typical model. This study basically allowed the D-T campaign to proceed. Otherwise they would have needed a public evacuation plan. Princeton University was highly unlikely to condone an activity that required a public evacuation plan.

2) The EQE company seismic safety walkdown. This consulting engineering firm (www.eqe.com) specializes in seismic safety and performed a walkdown inspection of the TFTR in June 1993. Based on the recommendations by the inspectors, they added some seismic anchorage to TFTR and its piping.

Jerry noted that there was less emphasis on worker safety in the SARs in those early years, only public safety was specifically addressed. In the last ~10 years there has been more USDOE emphasis on determining the safety of workers at USDOE facilities.

The next speaker was Dr. Martin Dentan from the Joint European Torus (JET). He has been working at JET for over a year. Before that he worked at CERN, in high energy physics.

JET was operated under the JET Joint Undertaking until end 1999. The JET Operating Contract was signed in end 1999 in the frame of the European Fusion Development Agreement (EFDA) and is expected to be extended upon expiration on 31 December 2004.

JET has had 10 campaigns since the JET Operating Contract was signed. Each campaign is usually between 10 to 30 experiment days. The operations are intensive, about 130 operating days per year, 2 sessions per day. Both operating sessions sum to a total of 12.5 hours in a day. The typical number of JET pulses is ~25/day. JET requires about 30-minute inter-pulse time to cool the magnet coils, as well as set up the scenario for heating the plasma and to download the data from the previous shot. This inter-pulse time depends on the experimental programme (higher fields needs longer cooling times, complicated heating system scenarios requires long set-up times, complex new physics scenarios requires more thinking time).

Equipment failures may induce delays (no pulse launched until the fault is fixed) or restrictions (pulses are launched with some restrictions). Cumulated delays result in missing pulses (at JET, 30-min delay represents one missed pulse). Restrictions may impact the pulse physics parameters and hence the relevance of the physics results. This impact depends on the requested parameters. For example, high performance experiments often require the maximum installed neutral beam injection power; in such a case there is no reserve to make up for a fault and any temporary NBI fault is likely to reduce the relevance of the pulse physics results. In less demanding experiments, it is often possible to make up for temporary faults in order to achieve the desired pulse physics parameters and hence to obtain relevant physics results.

Depending on the delays and on the average inter-pulse time, the total number of attempted pulses in a campaign can differ from the initial target. Attempted pulses that do not fail are successful pulses, which include dry pulses, recovery pulses, and pulses dedicated to physics. Pulses dedicated to physics are rated against their physics results. Good physics pulses (rated 2 or 3 stars) are those which meet the desired pulse parameters. Less satisfactory pulses (rated 0 or 1 stars) are those which may be wholly acceptable from the plasma point of view, but did not meet the desired pulse parameters.

JET performs statistical analyses of its operations, including the percentage of good physics pulses and other detailed technical indicators (restrictions, delays, successful pulses, pulses dedicated to physics, etc.). For example, the C-9 campaign plan (reverse magnetic field) called for 250 pulses. This campaign was not very demanding, so in spite of operation delays equivalent to about 25 pulses, 275 pulses were achieved. Among them, 251 were successful. They gave 232 pulses dedicated to physics, among which 166 good physics pulses (which represents 66.4% of the targeted pulses) and 66 less satisfactory pulses (which represents 33.6% of the targeted pulses). More demanding campaigns such as C-10 (high performance experiments) gave smaller fraction of good physics pulses.

In some campaigns, less satisfactory pulses correlate well with plots of faulty systems. For instance, during C-10, most of the neutral beam heating system faults cause less satisfactory pulses (correlation coefficient: 90%), because these systems were requested with their maximum installed power.

There are "scarce resources" limitations on pulses. This does not necessarily refer to funding. Non-funding scarce resources at JET are: Radiation (dose rate, neutron flux), Toroidal Field Coil fatigue, Disruption forces on the vessel, and Tritium consumption.

JET is in the C-11 campaign (trace tritium experiments) at this time. This campaign is going well.

Next, Tonio Pinna spoke about the report he recently completed on JET vacuum component and active gas handling system (AGHS) components. He had also reviewed Tritium Laboratory-Karlsruhe (TLK) data on tritium-bearing components. There are 6,259 components in the AGHS at JET. Obtaining the component counts and the operating hours for the components was a tedious task. There were 130 failures over 6,259 components that have operated for a total of 156,767,000 unit-hours, from 1995 to January 2002. There have been ~50 valve faults, including fail to open, fail to close, and external leakage.

Tonio discussed the JET vacuum vessel, there are 8 octants that comprise the vessel and each octant has 5 sectors. They were able to establish a parts count, but it was very difficult. He used drawings of the single components; the drawings were retrieved from the drawing office archive. Many of the components no longer were in use on the JET machine, and it was very difficult to establish the dates of installation and removal of the components on the torus parts. Many of the original staff had retired or left for other work and were not available to discuss JET components with Tonio. Tonio constructed tables of vacuum vessel modifications over time and also estimated the time that JET has been under vacuum. There were 2375 components in the vacuum system. John Orchard at JET had kept a vacuum leak database that was very complete; unfortunately John retired last year.

The Tritium Laboratory Karlsruhe (TLK) has a component count of 584 components, but the total operating time is low, so Tonio is not as confident in these component failure rates as he is in the JET values.

Tonio plans to look at JET neutral beam injectors and power supplies as the next systems to study. This work is in progress and should be finished in the first half of next year.

> Ray Camp stated that the four major issues they had with tritium systems on the TFTR were valve seals that leaked and required replacement, scroll pumps failing that required replacement, instrumentation problems, and tritium monitors that would become contaminated by water. These are the same four issues that Tonio has found from the JET AGHS. Ray said that was very consistent, amazingly consistent, and that it shows the technical, if not statistical, accuracy of these data.

Then Tony Natalizio presented initial work on ITER Worker Dose Assessments to support preliminary licensing assessments of the ITER design. The safety focus is often on public safety, and ITER needed more work on personnel safety, especially with all of the cooling systems that are in the ITER plant. The ITER target dose is 2 mSv for workers. Tony's task is to collect historical data from present experiments and other pertinent sources.

In the preliminary findings thus far, maintenance is the main contributor to worker doses, which is the long-standing belief held by the fusion community. Judging from the actual data, the tradesmen and technical support personnel receive about 2/3 of the yearly radiological exposure. This 2/3 value is not as high as was first anticipated. The system engineers receive more dose than was anticipated. This is probably due to visits to the system to help tradesmen and to inspect the work that has been completed.

In most facilities, a committee sets the dose goal for the upcoming work year. If the collective worker dose is less than the dose goal, there are questions as to why the goal was pessimistically high. If the actual collective dose exceeds the goal, there are questions as to why the dose goal was so optimistically low.

Ray Camp, the Chief Operations Engineer (COE) on the NSTX, spoke about the NSTX trouble report system and data collection at NSTX. Ray showed us the NSTX web site at http://nstx.pppl.gov/. This site can be visited to see the availability statistics for the machine. Other links on that page are not available to persons outside of PPPL.

Ray showed us some of the statistics for NSTX. For the monthly runs in the 2002 operating campaign, NSTX availability was:

February 91.4%
March 92.8%
April 81.3%
May 96.3%
June 92.8%
(Then the machine was in a maintenance shutdown for the rest of the year.)

In February 2003 the machine had a magnet fault, and has been under repairs and upgrades before resuming plasma operations.

The COE records the machine up/down status in the availability log at the beginning of each day. If NSTX is not ready to go to a test shot or plasma attempt after 15 minutes due to some subsystem problem, then NSTX is down and the COE will record which subsystem is responsible for the down time. Time spent thinking about what to do next is not considered to be down time, since NSTX could run if there was direction. If NSTX makes a plasma attempt and all systems function as directed but do not result in the expected plasma is not charged as down time because the systems did work. The data do not show the issue that you can have a run day that had only a few plasma attempts but also had very little down time because test shots were being performed, or much of the day was spent thinking about what to do next.

NSTX documents which subsystems impact the machine availability so that they can better understand the problem areas, track resolutions and predict if there are any negative trends. NSTX has an on-line trouble report system. (see the paper by S. Sengupta and G. Oliaro, "The NSTX Trouble Reporting System," Proceedings of the 19th Symposium on Fusion Engineering, January 22-25, 2002, Atlantic City, NJ, IEEE 2002, pages 242-244.)

The NSTX staff also keeps track of the number of plasma attempts and use this as another measure of how many run days that have been completed. They can add additional run hours to catch up from bad run days, like Dr. Dentan described can be done at JET. An NSTX run day is 8 hours and the first hour is used to perform test shots and hipot tests, then the remaining time would give 28 plasma shots at 15 minutes/shot. Over the NSTX operating time thus far, they have reached these statistics:

Fiscal Year	**NSTX Run Weeks**	**Total Number of Plasma Attempts**	**Plasma Attempts per Day**
2000	15	2,504	> 33
2001	15	2,137	> 28
2002	13	1,928	> 29
2003	4.25	603	> 27

The NSTX availability log also records the number of completed usable plasmas as compared to the number of unusable plasmas (fizzles, aborts, etc.). This comparison of good plasmas to plasma attempts provides a "quality factor" or reliability metric.

Ray summarized his discussion:
NSTX tracks machine availability and system failures in the following ways:
-System availability of up versus down time on scheduled run days or run hours
-A log system to document and track subsystem problems and record the number of plasma attempts in a given run period
-Tracking the number of usable plasmas that result from the number of plasma attempts

After lunch, we were given a detailed tour of the NSTX facility by Alfred VonHalle, the NSTX Operations Manager. We even were able to see the interior of the machine since it was opened for upgrades while the magnet coil is under repair. Some photographs from the tour will be placed on the web site.

After the tour, Lee Cadwallader gave an overview of US failure rate data work. The talk had several parts – generic data harvesting, data analysis from DIII-D and tritium component data. At the 2002 task meeting, it was agreed to perform a generic data harvest on remote handling data, and this task was initiated in 2003. But the task was placed on hold and deferred into 2004. The data analysis from DIII-D data has been positive thus far. Vacuum components were examined for leakage failures and were reported on at the 15th Topical Meeting on the Technology of Fusion Energy last November, and personnel safety sensors for oxygen content in the air were analyzed this year. For monitors failing to operate, the failure rate is 2.6E-06/h with an upper bound of 1.1E-05/h, and the false alarm frequency is 4.6E-05/h with an upper bound of 7.4E-05/h. The results will be presented at the 20th Symposium on Fusion Engineering in October 2003. One system or component analysis per year is planned for the DIII-D data. The remote handling data harvest will continue in 2004. The issue of tritium component failure data arose when Los Alamos personnel sent the remainder of their trouble report database to Lee in the summer of 2003. A proposal to update the failure rates from Los Alamos and then compare the data to Japanese, European, and any generic data was suggested. A limited comparison will validate the data.

Lee Cadwallader then presented information on task participants who could not attend the meeting. There has not been much communication with these participants, such as Mohamed Eid, who is busy with conferences, and Boris Kolbasov, who is busy with ITER. The main participants did attend the meeting.

The roundtable discussion dwelt on ITER:

- The reliability data needs for ITER licensing were discussed – but we are in a holding place while we wait for ITER siting to proceed.

- France uses deterministic safety analysis (no failure rates needed)
- Spain would require some probabilistic safety work (failure rates needed)
- Canada would require some probabilistic safety work
- Japan is not known, we suspect it is primarily deterministic safety analysis

• Discussion of the tritium plant component data brought up this point – the regulators know that tritium plants operate now, with off-the-shelf components. We should not spend a great deal of time with comparisons of tritium data when the safety of tritium plants is better known than other parts of the ITER facility. For example, tritium plants have already operated safely in Canada and in the US (Savannah River, Mound, TSTA, etc.).

• The main task at hand now is ITER. Our focus should be on ITER support.

• The Task Coordinator must make more effort to involve the Japanese, in both failure rate work and in Occupational Radiation Exposure work. Data from JT-60U and LHD would be beneficial to the ORE study and to the failure rate data analysis task.

• We have limited resources; we must focus on important reliability issues instead of safety issues. We do not have the people or funds to approach all of the safety issues that will arise.

• Systems important for near-term work are vacuum systems because the vacuum boundary is the first confinement boundary. Neutral Beam Injection systems as well, since these heating and diagnostic systems are also a part of the first confinement boundary. ITER has 3 heating NBI and one diagnostic NBI. The vacuum boundary will be the most unusual engineered system to nuclear regulators. We should study diagnostics that penetrate the vacuum boundary as well.

The next task meeting will be held at JET, tentatively in the spring of 2005.

The meeting was adjourned at approximately 5:30 pm.

Meeting Attendees:

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